Filter Radiometer Monitoring System PDR

NASA GSFC Code 920.1
Laboratory for Terrestrial Physics
Calibration Facility

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John Marketon
NASA GSFC Code 920.1
Greenbelt, MD 20771
(301)614-5950
email john.marketon@gsfc.nasa.gov

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Abstract

As spherical integrating sources age, interior surface and lamp degradation result in radiance output level shifts. Radiance output shifts compromise instrument and source calibration accuracy. Monitoring radiance output of a source over time can provide insight to the origin of the calibration error. The Code 920.1 Calibration Facility (CF) currently does not monitor source radiance output levels. This results in a higher uncertainty than is desirable for a calibration. This document defines the preliminary design for a Filter Radiometer Monitoring System (FRMS).

Goals

- Monitor source output level over time in multiple bands to detect changes.

In addition to detecting output level shifts, FRMS data has several additional uses, including:

1. Determining relative humidity (RH) levels by correlating measured water absorption within the sphere with other types of RH measurements.
2. Prediction of service intervals for lamp replacement and source resurfacing.
3. Collect monitoring data in common remote sensing bands.
4. Closed loop feedback control for a constant radiance source.

System Requirements

Parameter	Requirement	Approach
Spectral Bands	Water and Remote Sensing bands	Bandpass filters on a rotating filter wheel. Filter λ centers @ 410, 440, 640, 840, 1040, 1250, 1380, 1650, 1875, 2200 nm. Two detectors covering wavelength range: Si for 180 – 1100 nm bands PbS for 1000 – 2500 nm bands
Spectral Bandwidth	50nm @ 1%, ≤1800nm 100nm @ 1%, >1800nm	Appropriate filter characteristic selection.
Sampling Speed	≥1 sample/minute/band	Filter wheel at ≥1 rpm Precision chopper
Resolution	Detect ≤1% change	Chopper stabilized signal. Lock-in amplifier
Stability	Maximize	Thermally stabilized detectors (Si & PbS) Pre-amps close to detectors. Digital Lock-in Chopper stabilized signal.

Heritage

The FRMS is a classic, well-understood design, simpler than other instruments currently in use within the CF. Familiar components will be extensively used. For example, the filter wheel positioning motor and controller are identical to those used on the HX instrument grating positioning cam. FRMS detectors are fundamentally similar to other detectors used on CF instruments. Though an instrument like FRMS is not presently in CF inventory, using familiar components and subsystems minimizes uncertainty and risk.

System Concept

The monitor detector head is affixed to a source, sampling the source output during operation. Bandpass filters select the spectral band of interest. Some bands of interest have relatively low signal levels, suggesting use of ac signal recovery techniques. The bands of interest are in the visible and near-infrared spectral regions, requiring the use of two sensors, one for each region.

Optical

The FRMS optical design includes only the detector, an aperture, baffles, a field stop, filters, and a chopper (see Figure 1). Lenses and mirrors are not required since the FRMS does not image, nor is there a volume problem. For mechanical convenience, the chopper is in the middle of the optical system, rather than in front, which adversely affects thermal IR measurements. Since the FRMS bands of interest are not in the thermal IR, this arrangement is adequate for the application.

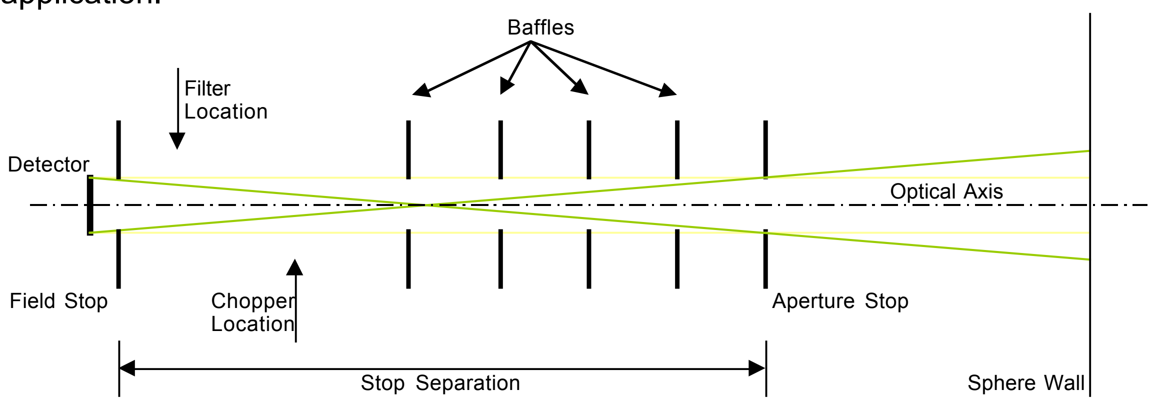

Figure 1 – FRMS Optical Design

Internal stray light is reduced by the baffles and by blackening internal components. The blackening proposed is Martin Black, or similar, aluminum anodizing process which has good absorption characteristics in the 300-2500nm spectral region.

Field of View

For FRMS, it is useful, but not critical, to determine the field of view (FOV = 2θ). The aperture and field stop diameters are determined by the required detector fill area and sphere footprint (see Figure 2).

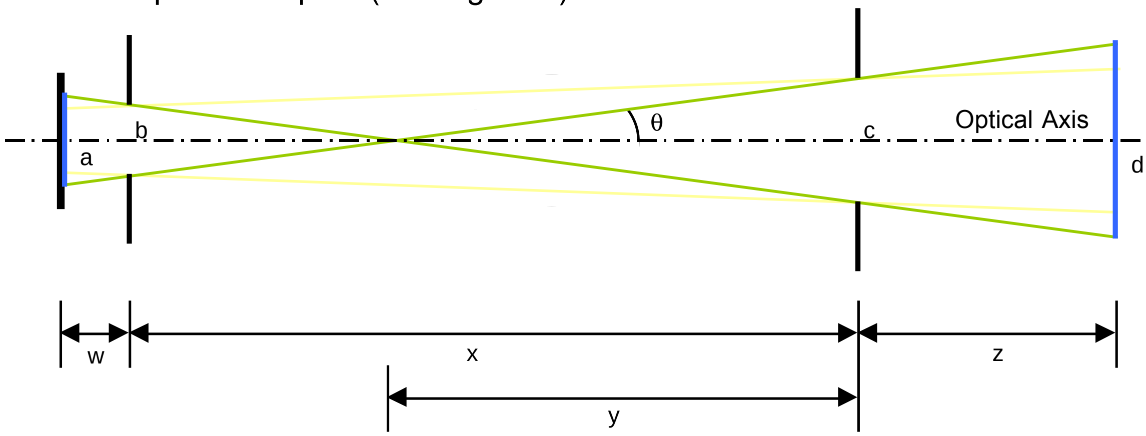

Figure 2 –Optical Calculations Diagram

Given **a**, **d**, **w**, **x**, and **z**, the other variables (**y**, **b**, **c**, and θ) may be calculated by:

$$\tan\theta = \frac{a}{2(x - y + w)} = \frac{b}{2(x - y)} \qquad \tan\theta = \frac{b + c}{2x}$$

$$\tan\theta = \frac{d}{2(y + z)} = \frac{c}{2y} \qquad y = \frac{x + w - \frac{a}{d}z}{\frac{a}{d} + 1}$$

Detectors

The spectral bands of interest lie in both the visible and near infrared (NIR) regions. This dictates a requirement for two detectors, a Si detector for the visible, and a PbS for the NIR. To stabilize detectivity, the detectors must be thermally controlled to improve both signal to noise ratio, and short- and long-term stability,.

The selected detectors are the Hamamatsu S2592-03 (Si) and P2682-01 (PbS). The Si detector is mounted on a single stage thermo-electric cooler (TEC), the PbS on a dual stage TEC. To measure temperature, a thermistor is mounted next to each detector. The exact detector temperature is non-critical, but maintaining a fixed temperature is critical. This is accomplished by using the Hamamatsu C1103 temperature controller. Active area for the Si detector is $2.4mm^2$. Active area for the PbS detector is 4x5mm.

Filters

Given the largest beam diameter (for PbS) is under 6mm, a filter diameter of 12.5mm (1/2”) is adequate, and is a standard filter size.

Chopper

The chopper is a Stanford Research SR540 Optical Chopper modified to include a feedback speed control. This modification consists of adding a shaft-mounted tachometer to the chopper motor from which a speed adjustment signal is derived and fed back into the SR540 chopper controller.

The PbS detector specifications are quoted at a 600Hz chop frequency. With a six slot blade, the chopper motor setting this is 100rpm.

The Si detector specifications quote a 0.2μs rise time, corresponding to a maximum frequency of 5MHz. Thus, a 600Hz chop frequency is well within the Si detector capabilities.

Mechanical

The FRMS detector head combines the filter wheel and motor with encoder, chopper blade and motor with tachometer, two detectors, and an aperture/baffle tube for each detector (see Figure 3 and Figure 4).

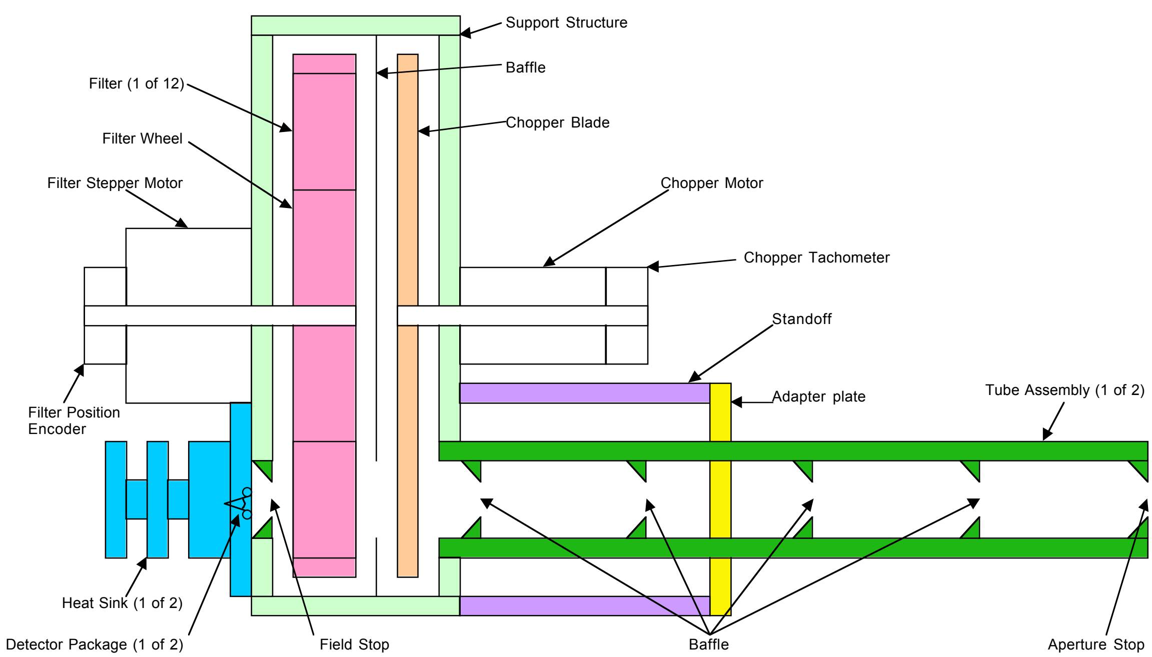

Figure 3 – FRMS Side View

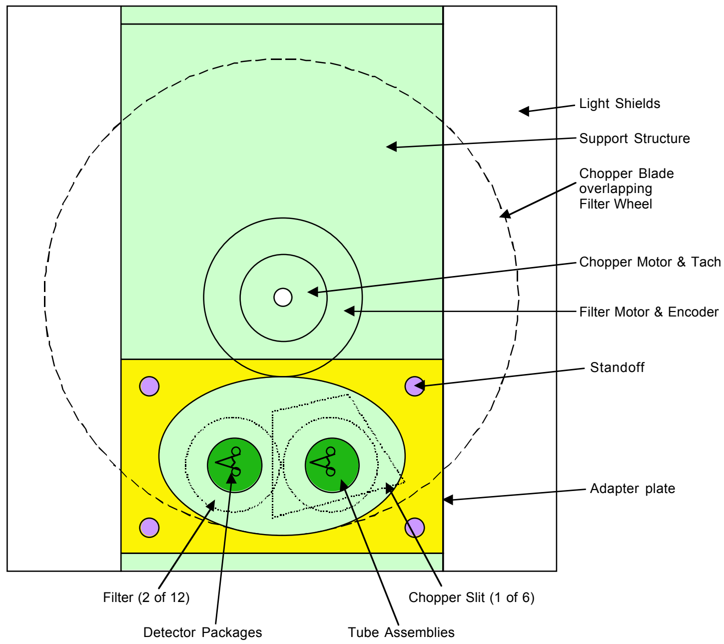

Figure 4 – FRMS Front View

A central support structure provides attachment points for the motors, detectors, mounts, etc. The filter stepper motor shaft provides a direct mechanical link for the filter wheel and filter position encoder. Likewise, the chopper motor shaft provides a direct mechanical link for the chopper blade and the chopper tachometer. In both cases, the motors are mounted external to the support structure. To minimize stray light, a baffle is placed between the chopper and filter wheel. To enclose the chopper and filter, caps are fastened to both sides of the support structure. The filter wheel accommodates twelve (12) filters.

The detector assemblies fasten to the rear of the support structure. Within each detector package is a detector, a thermistor for temperature sensing, and a TEC. The major volume of the detector package is the heat sink for the TEC.

Attached to the front of the support structure are two self-supporting tube assemblies. The tubes are segmented and threaded. The baffles drop into position, and are held in place by screwing the segments together. The tubes are screwed into threaded receptacles on the primary support structure. This assembly method simplifies customization of baffle quantity and size as well as tube length.

A front adapter plate permits easy attachment to the monitor ports presently mounted on Laurel and Hardy (see Figure 5). Port depth on these two sources differs, and the correct depth is reached by adjusting the standoff length.

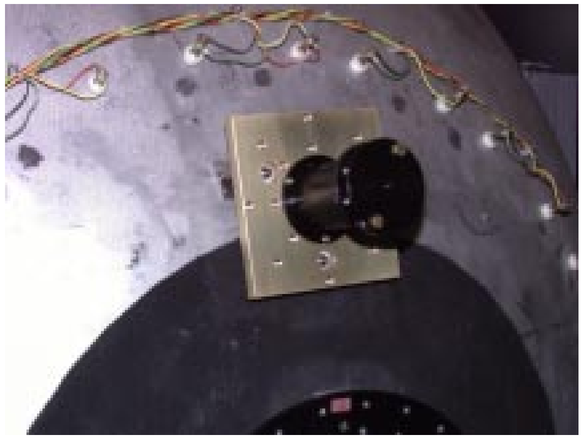

Figure 5 –Monitor Port on Hardy

Electrical

The filter wheel, signal recovery, chopper, and detector subsystems comprise the FRMS electrical system. There are two identical signal recovery subsystems, one for each detector. These subsystems are connected to the Macintosh control computer via GPIB (see Figure 6).

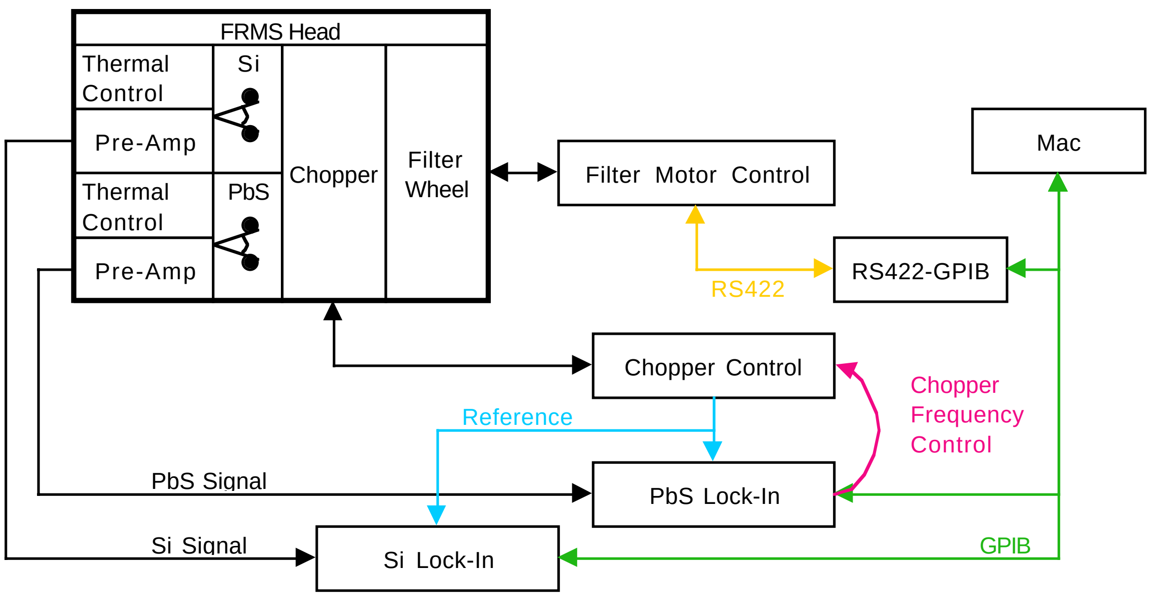

Figure 6 – FRMS Electrical Block Diagram

Filter Wheel

A stepper motor controller operates the filter wheel stepper motor. A rotary position encoder with a home mark provides the necessary feedback to accurately position the filter wheel. The Macintosh control computer communicates with the controller via the built-in RS422 interface. An RS422 to GPIB converter performs the necessary interface conversion.

Signal Recovery

Pre-amplifiers for both detectors are placed as close as possible to the detector head, minimizing noise pickup. To permit measurement of low radiance levels, for example in the UV and NIR regions, lock-in amplifiers are used. This classic, well understood technique poses no significant implementation problems. A chopper interrupts the input signal, and provides the reference frequency to both lock-ins.

Chopper

The chopper is a stand-alone system, which does not require computer intervention. The chopper controller includes a control input to remotely adjust the chopper speed. Chopper speed is obtained by reading the reference input frequency measurement of the lock-in amplifiers. The lock-in amplifiers include several DAC output channels; one output channel on the PbS lock-in is used as the chopper speed control. To maximize measurement throughput, the chopper uses feedback to precisely control the chopper speed, providing a stable reference frequency.

Detectors

Two detectors are used, Si and PbS, sensitive to different spectral regions. However, both detectors are temperature stabilized. This stabilization is accomplished by placing the detector and a thermistor on a thermo-electric cooler (TEC). A temperature controller maintains the thermistor at a preset value by adjusting the current through the TEC, cooling or warming the detector. The target PbS operating temperature is –20°C, while the Si temperature is –10°C.

Breadboard Testing

An FRMS breadboard was constructed for experimental verification of the proposed concepts (see Figure 7).

Figure 7 – FRMS Breadboard and Closeup

Though there were some differences between breadboard and proposal, the breadboard validated the FRMS concept. The differences between breadboard and proposal are:

- Detectors were a different model, but similar type, and were not thermally stabilized.
- Filters used were not optimal, and wavelength selection was limited.
- Baffles and apertures were not installed on the inlet tube, resulting in some stray light and a wider field of view.
- The sources used were significantly dimmer than the brightest CF source.

The following conclusions were drawn from the breadboard testing:

- Chopper speed stability is crucial to high-speed operation of the lock-in amplifier. This indicates the need for a chopper with feedback speed control.
- The detectable signal level is significantly lower than anticipated signal levels.
- Possible detector saturation in some bands.

Software

Function

FRMS software will be built on the SSF. Two modules are required: one to position the filter wheel, the second to set chopper speed and acquire measurements from the two lock-in amplifiers.

On initialization, the filter wheel is moved to the home position of PbS blocked, Si open. To take a monitor sample, both the Si and PbS lock-in measurements are recorded. The filter wheel is rotated the next position, and some settling time is allowed. These two steps are repeated for each of the filter positions, returning to the home position. The next monitor sample begins after the calculated inter-sample duration for the specified sampling rate.

Data Collected

Each FRMS sample consists of up to 24 measurements. Each measurement corresponds to detector / filter pair measurement.

Data Storage & Dissemination

Raw data are stored as binary files. These files will be available for download through the CF web site, *http://spectral.gsfc.nasa.gov/*.

Operation

FRMS operation is completely automatic. When the Standard Source Power System (SSPS) indicates the source has stabilized, FRMS begins sampling at the specified rate. When the SSPS indicates a shutdown state, FRMS stops sampling. The sampled data is recorded as part of the source operation data log.

FRMS is removed from its source at specified intervals for characterization.

If a different spectral band set is to be monitored, the filter wheel is removed from the FRMS, and the appropriate filter set installed. The filter wheel is then re-installed on the FRMS, and normal operation resumes.

Calibration

The FRMS is detecting short- and long-term relative changes. As a result, system calibration is not required, but determining system stability is critical. To monitor stability, the filter transfer characteristics will be measured on a semi-annual basis. If no change is detected after four measurements, annual characterization will commence. In addition to the filter transfer characterization, FRMS data will regularly be compared to the monthly sphere calibrations.

The operational filter set is regularly subjected to high radiance levels and large temperature changes. To determine if environmentally induced component degradation is an issue, spare and control component sets will be subjected to the same characterization testing as the operational component set. The spare and control sets will be stored in light-tight containers in a dry, inert atmosphere.

Cost

Estimated component cost to complete the FRMS Engineering Model is $7000 ±10%. Following is the cost breakdown for the Engineering Model.

Fabrication	$3000
Filters	$1000
Chopper with feedback speed control	$2000
Electrical & Electronic Components	$500
Mechanical and Electromechanical Components	$500

This does not reflect the cost of components already in CF inventory, including detectors, pre-amplifiers, temperature controllers, and lock-in amplifiers.

Estimated cost of each FRMS operational unit is $24k ±10%. This figure does not account for minimum quantities or quantity discounts. Following is the cost breakdown per operational units.

Fabrication ‡	$3500
Bandpass Filters ‡‡	$3500
Digital Lock-In Amplifier, 2 @ 4000	$8000
Si & PbS Detector Systems	$5000
Includes thermally stabilized detectors, pre-amplifiers, heat sinks, and TEC controllers	
Chopper with feedback speed control	$2000
Filter Wheel motion control	$1000
Wiring and other supplies	$1000

‡ Quantities greater than one will reduce this per unit cost
‡‡ Minimum quantities may increase this per-unit cost

Schedule & Manpower

Completion to a basic operational state is about 12 weeks. Projected start date is early Dec 1999. Schedule breakdown follows:

Component designs	3 MW
Fabrication	3 MW*
Component procurement	6 MW*
Programming	4 MW*
Integration & Test	3 MW
	* In parallel
	MW = Man Week